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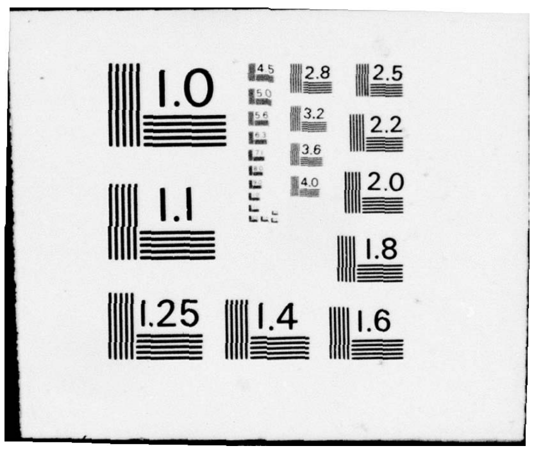
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FINE SCALE RADIO STUDIES OF THE SUN

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15 July 1976

FINAL TECHNICAL REPORT
1 June 1975 - 30 June 1976

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(9) Final technical rept. 1 Jun 75-30 Jun 76

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) (18) AFGL-TR-76-0167	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) FINE SCALE RADIO STUDIES OF THE SUN.		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report 1 June 1975 - 30 June 1976
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Kenneth R. Lang		8. CONTRACT OR GRANT NUMBER(s) (15) F 19628-76-C-0020 NEW
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics, Tufts University, Medford, Massachusetts 02155		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4643-03-02, 62101F
11. CONTROLLING OFFICE NAME AND ADDRESS AIR FORCE GEOPHYSICS LABORATORY, Hanscom Air Force Base, Mass. 01731, Contract Monitor: Ronald M. Straka/PHP		12. REPORT DATE (11) 15 Jul[redacted]76
		13. NUMBER OF PAGES 15 (12) 16p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (16) AF-4643 (17) 464303		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Portions of this report will be published in Solar Physics

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Solar Flare Prediction, Radio Interferometry, Polarization,

Fine Angular Scales, Solar Radio

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

ABSTRACT

Major flare eruptions in solar active regions create geophysical disturbances that may seriously disrupt Air Force communication and surveillance systems. Preliminary interferometric observations of the Sun by the principal investigator revealed significant changes in the fine scale structure of the region hours in advance of a flare eruption. The present contractual effort sought to confirm this vital observation and to obtain more information on the

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BLOCK 20. ABSTRACT (cont.)

CONT

small-sized flare trigger sources that could be applied in a reliable flare forecast technique.

For the current interferometric observations of the Sun the four Stokes parameters are presented at wavelengths of $\lambda = 3.7$ cm and $\lambda = 11$ cm with angular resolutions between 2.7 and 36.7 seconds of arc. An Hα solar flare of importance SN and type C was detected which had a radio wavelength ($\lambda = 3.7$ cm) size of 5 seconds of arc, a flux density of 0.3×10^{-22} W m^{-2} Hz^{-1}, and a brightness temperature of the order of 10^7K. The radio flare was 30% left circularly polarized at $\lambda = 3.7$ cm, 70% left circularly polarized at $\lambda = 11$ cm, and had no detectable linear polarization at either wavelength. During a forty-hour observation of sunspot region McMath No 13926 no substantial variations in circular polarization were observed, whereas one hour prior to the eruption of a solar flare dramatic changes in circular polarization were observed. Small scale features whose angular sizes are on the order of five seconds of arc exhibit changes of circular polarization of up to 80%. At times other than those immediately preceding flare emission, the degree of circular polarization was the same at the two wavelengths but the sign was reversed. This situation can be explained if magnetic fields of intensity $H \leq 1000$ gauss and electron densities of $N_e \geq 10^7$ cm^{-3} are present.

I. INTRODUCTION

Ever since the work of Gold and Hoyle (1960), it has been known that the seat of energy for solar flare emission must lie in the magnetic field of sunspots. The strength of the magnetic field is reflected in both the intensity and degree of circular polarization of the solar radio emission at centimeter wavelengths. Tanaka and Kakinuma (1962), for example, have shown that the slowly varying component emitted by sunspots at centimeter wavelengths is 20 to 30% circularly polarized, and that intensity of the radio emission is related to the number and size of the sunspots. Kundu (1959) pointed out that the intensity of the polarized component increases greatly at times of high solar activity; and other observers have shown that the degree of circular polarization exhibits substantial variation both prior to and during the emission of solar flares (Straka, Richards, and Arora, 1972; Kaufman and Santos, 1974; and Papagiannis and Kogut, 1975). The degree of circular polarization has been observed to change between 3 and 20 percent in time intervals of a few minutes to one half hour before the emission of flares, and similar changes are exhibited during the emission of the flare itself. The general picture is one in which the emergence of magnetic fields which trigger solar flares is reflected in changes in circular polarization prior to flare emission; whereas the movements and magnetic changes in the burst sources are seen as changes in circular polarization during flare emission.

It has only recently been realized that the observed changes in circular polarization are diluted by the large beamwidths being used. This is essentially because the scale length of the magnetic field in sunspots is of the order of seconds of arc in size (one second of arc equals 700 km on the solar surface), whereas the beamwidths used in the previously mentioned observations are several minutes of arc in size. By using a radio frequency interferometer (wavelength λ = 3.7 cm) with a resolution of 7 seconds of arc, Lang (1974a) was able to show that small scale features in the sunspot regions change from 30% to nearly 100% circular polarization prior to the emission of solar flares and that changes in the intensity of this component during the subsequent flare emission suggest outward travelling waves with velocities on the order of the Alfvén velocity in the outer regions of sunspots.

On the basis of this preliminary observation, it was thought that centimeter wavelength radio interferometry of the sun would provide a much more sensitive means for predicting flare emission, and for studying the motions of the material and magnetic fields within the flaring regions. A general program was therefore set up under the sponsorship of the AFCRL in order to simultaneously measure the four Stokes parameters of solar radio emission at wavelengths of λ = 3.7 cm and λ = 11 cm with angular resolutions ranging from 2.7 to 36.7 seconds of arc. The subsequent observations at the National Radio Astronomy Observatory have confirmed the emergence of fine scale features with circular polarization changes between 40% and 100% prior to the emergence of a subflare.

II. OBSERVATIONAL FACILITIES

(a) Description of facility used for this contract.

The observations reported in this report were made using the three-element interferometer system of the National Radio Astronomy Observatory between May 15 and May 20, 1975 and between November 5 and November 10, 1975. A dual channel system was used at signal frequencies of 2695 MHz (λ = 11 cm) and 8085 MHz (λ = 3.7 cm) with circularly polarized feeds, an intermediate frequency bandwidth of 30 MHz and an integration time of 30 seconds. The three 25.9-m diameter paraboloids were placed on a skewed baseline with linear phase center displacements, B, of 600, 2100, and 2700 m. These baselines provided effective angular resolutions, $\theta = \lambda/B$, of 12.3, 3.5, and 2.7 seconds of arc, respectively, at λ = 3.7 cm, and 36.7, 10.5, and 8.1 seconds of arc, respectively, at λ = 11 cm. All four Stokes parameters were measured at one minute intervals for all six sets of baselines and wavelengths. The parametric amplifiers were bypassed, and the system noise temperature was completely dominated by the solar brightness temperature of 2×10^4 ^oK. For these observational conditions the theoretical r.m.s. noise fluctuation in fringe amplitude was 10 f.u., where 1 f.u. = 10^{-23} erg s^{-1} cm^{-2} Hz^{-1}. Observations of the radio sources 3C 84 and 3C 273 were used, respectively, to calibrate the May and November observations. In the calibration procedure it was assumed that 3C 84 had respective flux densities and linear polarizations of 16.5 f.u. and 1.1% at λ = 11 cm and 52.4 f.u. and 0.9% at λ = 3.7 cm. For 3C 273 the assumed flux densities and linear polarizations were 30 f.u. and 2.0% at λ = 11 cm and 40 f.u. and 1.4% at λ = 3.7 cm. By using these calibrators, the total intensity of the fringe amplitudes of the sun were normalized into flux units with an uncertainty of a few flux units, and the circular polarization data were expressed as a percentage with an accuracy of less than 10%. Because the solar data exhibit circular polarizations of up to 100%, the rather large uncertainties do not effect any of the conclusions. These conclusions are presented in section III of this report.

(b) Description of other available facilities

Other than the National Radio Astronomy Observatory (see section (a) above), fine scale radio studies of the sun can only be performed at the interferometric facilities at Owens Valley, California and at the Haystack Observatory in Massachusetts. The principal investigator has therefore submitted a proposal for his use of the Owens Valley facility for solar studies next fall and/or winter. A technical proposal for the use of the Haystack-Westford interferometric system has also been submitted.

III. RESULTS ACHIEVED

The results of the solar interferometric observations performed under contract F 19628-76-C-0020 at the National Radio Astronomy Observatory may be conveniently divided into three groups: changes in circular polarization prior to flare emission, changes in circular polarization with observing wavelength, and the small-scale, quasi-periodic disk component of solar radio emission. The first two groups are discussed in subsections A and B which follow, and these results have been accepted for publication in Solar Physics in a paper entitled "High Resolution Polarimetry of the Sun at 3.7 cm and 11 cm Wavelengths". The quasi-periodic emission is discussed in subsection C, and this work will be the subject of a future letter to the journals. It is of interest that the Stanford radio astronomy group has recently confirmed the author's detection of a 5 mHz oscillation of the radio sun.

A. Changes in Circular Polarization Prior to Flare Emission

Between November 5 and November 10, 1975 the N.R.A.O. interferometer was used to observe the active region McMath No. 13926 as it crossed the sun from the east limb to the sun center. The approximate solar coordinates of the sunspot region were obtained from the Sagamore Hill facility; and during most of the observing time the peak of the radio emission at λ = 3.7 cm was obtained by simultaneous observations at the Haystack Observatory. The quick scanning properties of the Haystack facility were often instrumental in obtaining the exact coordinates of the sunspot region.

For any given day between November 5 and November 9, the degree of circular polarization of the active region remained constant within 10% during the 12 daylight observing hours. For all wavelengths and baselines used, the degree of circular polarization was below 30% for all four days. There was, however, a slow, approximately linear increase in the degree of circular polarization from $\sim$5% on November 5 to $\sim$30% on November 9 for all baselines at λ = 3.7 cm. This systematic trend is probably related to projection effects in which the angle between the line of sight and the direction of the magnetic field slowly becomes smaller as the sunspot moves from the solar limb to the center of the solar disk. What is of interest here is that these directional effects are present at angular resolutions of 2.7 seconds of arc, suggesting that the quiescent radiation being observed comes from the feet of bipolar spot groups.

Although the degree of circular polarization remained low (less than 30%) and constant (within 10%) for the 50-hour observing period between November 5 and 9, the active region suddenly exhibited a dramatic change to 100% circular polarization one hour prior to the emission of a subflare.

As illustrated in Figure 1, similar changes occurred about ten minutes before the flare and during the flare emission as well. In view of the fact that no similar changes are observed in the total radio intensity from the sunspot region (except for the flare emission itself), and in view of the fact that for 50 previous hours of observing the same region there were no similar large changes in circular polarization; we believe the observed changes in circular polarization are related to emerging magnetic fields which trigger the solar flare emission. The implications for predictions of flare emission are clearly evident.

B. Changes in Circular Polarization with Observational Wavelength

For the observations taken on November 8, 1975, the data taken at the two longer baselines (B = 2100 m and B = 2700 m) exhibited a phase reversal of 90° in the sense of circular polarization observed at the two wavelengths (λ = 3.7 cm and λ = 11 cm). The degree of circular polarization was roughly the same at the two wavelengths but the sign was reversed. This behavior can be attributed to coupling between the two magneto-ionic propagation modes. According to Cohen (1960), a change in the sense of circular polarization will occur when a circularly polarized wave generated in a region of quasi-longitudinal propagation subsequently passes through a region of quasi-transverse propagation. The requirement for the phase change is that the coupling ratio

$$Q \approx \frac{10^{-17}\ f^{4}}{NH^{3}\ L_{H}} << 1, \tag{1}$$

where our observing frequency is $f \approx 10^{10}$ Hz. and the angular size of 2.7 seconds of arc requires $L_H \approx 2 \times 10^{8}$ cm. Substituting these numbers into equation (1) we obtain

$$NH^3 >> 10^{15}, \qquad (2)$$

where N is the electron number density in cm^{-3} and H is the magnetic field strength in gauss. Fairly high values of electron density and magnetic field intensity are suggested.

C. The Small-Scale, Quasi-Periodic Disk Component of Solar Radiation

As first reported by Lang (1974), the centimeter wavelength emission coming from quiet disk regions varies in intensity with time scales ranging from 200 seconds to 400 seconds. The angular size of these time varying regions is of the order of ten seconds of arc. Kundu and Alissandrakis (1975) confirmed the presence of similar time variations at λ = 3.7 cm for angular sizes of about 2.5 seconds of arc. The latter authors, however, hesitated to assign any unique periodicity to the observed variations. In Figure 2 we reproduce their typical plot of visibility amplitude against time, and compare it with similar data taken during our quiet sun observations last May. Only a limited range of periodicities can fit the observed variations in both sets of data, and in this sense the variations can be termed quasi-periodic. We believe that the failure of the former authors to obtain spectral peaks from their data is due to the fact that their power spectra include data taken at the shorter baselines where the time variations are weakest. In this way they were adding noise to the observed signal illustrated is Figure 2, and could expect to obtain a noise-like power spectrum. We also provide in Figure 2 the degree of circular polarization, V, which is seen to be $\leq$ 10%. This failure to detect any significant degree of circular polarization gives further credence to the view that the observed variations are thermal bremsstrahlung rather than gyroradiation.

REFERENCES

Cohen , M. H.: 1960, Astrophys. J. 131, 665.

Gold, T. and Hoyle, F.: 1960, Mon. Not. Roy. Astr. Soc. 120, 7.

Kaufman, P. and Santos, P. M.: 1974, Astron. Astrophys. 34, 197.

Kundu, M. R.: 1959, Paris Symposium on Radio Astronomy (ed. R. N. Bracewell) Stanford Univ. Press, Stanford, p. 222.

Kundu, M. R. and Alissandrakis, C. E.: 1975, Mon. Not. Roy. Astr. Soc. 173, 65.

Lang, K. R.: 1974a, Solar Phys. 36, 351.

Lang, K. R.: 1974b, Astrophys. J. 192, 777.

Papagiannis, M. D. and Kogut, J. A.: 1975 Air Force Cambridge Res. Lab. Technical Rpt. 75-0430.

Straka, R. M., Richards, D. W. and Arora, K. K.: 1972, Bull. Am. Astron. Soc. 4, 392.

Tanaka, H. and Kakinuma, T.: 1962, J. Phys. Soc. Japan, Suppl. A-11 17. 211.

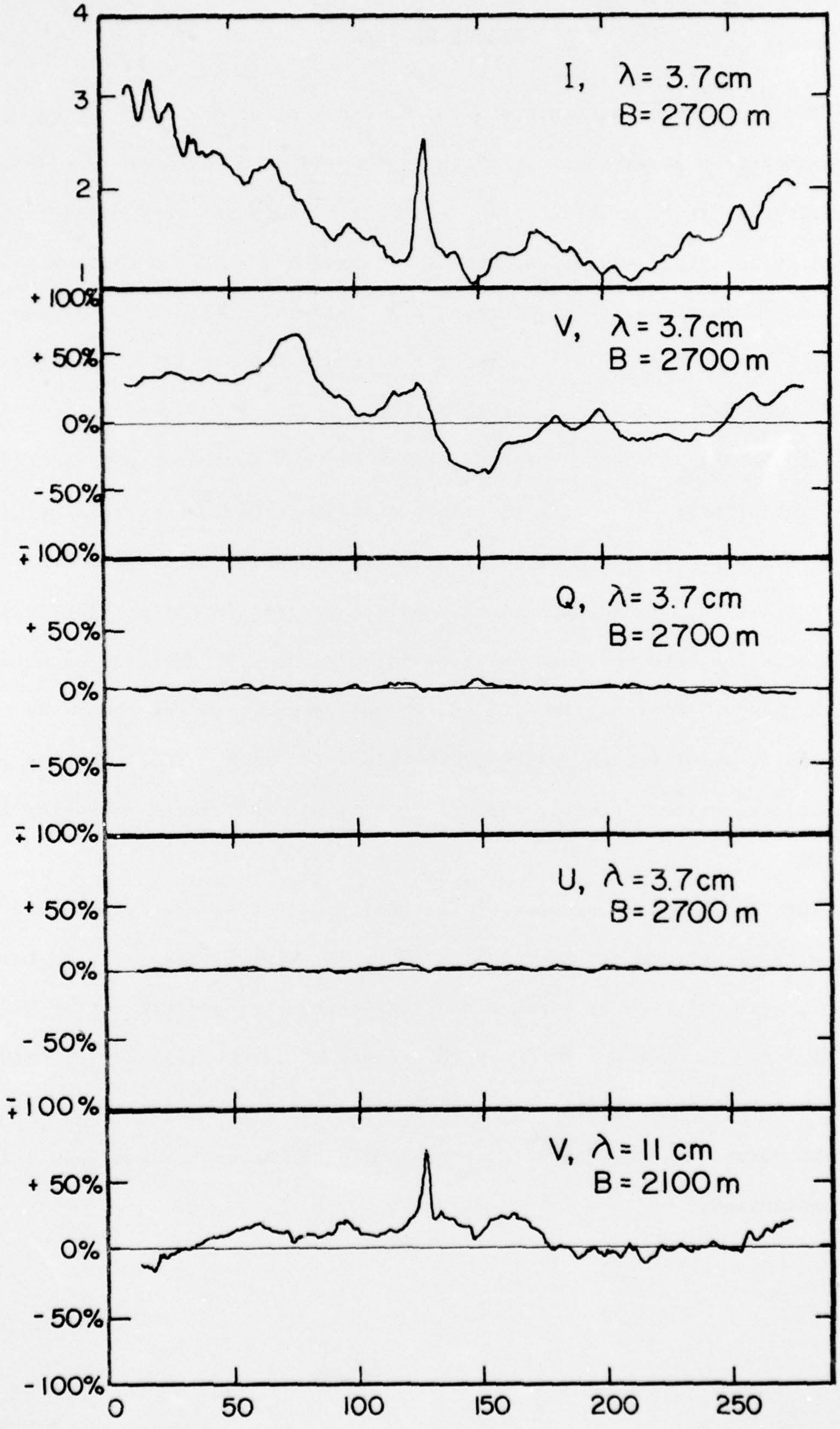
Solar Geophysical Data, Number 376-Part 1, December 1975.

FIGURE LEGENDS

Figure 1. The four Stokes parameters I, Q, U, and V plotted as a function of time for interferometric observations of McMath region 13926 on November 10, 1975. The total intensity, I, is in units of 10^{-23} W m^{-1} Hz^{-1} and positive V means left hand circularly polarized radiation. For a wavelength λ = 3.7 cm and a baseline B = 2700m, the maximum angular resolution is 2.7 seconds of arc. The narrow spike shown on the I record for λ = 3.7 cm and the V record for λ = 11 cm coincides with an Hα flare whose peak emission occurred at 14^h35^m U.T. The I record at λ = 11 cm is essentially identical to the V record at λ = 11 cm. No linear polarization was detected either prior to or during the flare emission. Of special interest are the dramatic increases in left hand circular polarization which occur at λ = 3.7 cm before flare emission. These changes have no counterpart in Hα emission or in total radio emission, and they are believed to be related to emerging magnetic fields which trigger solar flares. Of additional interest is the change in the sense of circular polarization following the flare emission. This change places severe constraints on the magnetic field intensity and the electron density in the flare region.

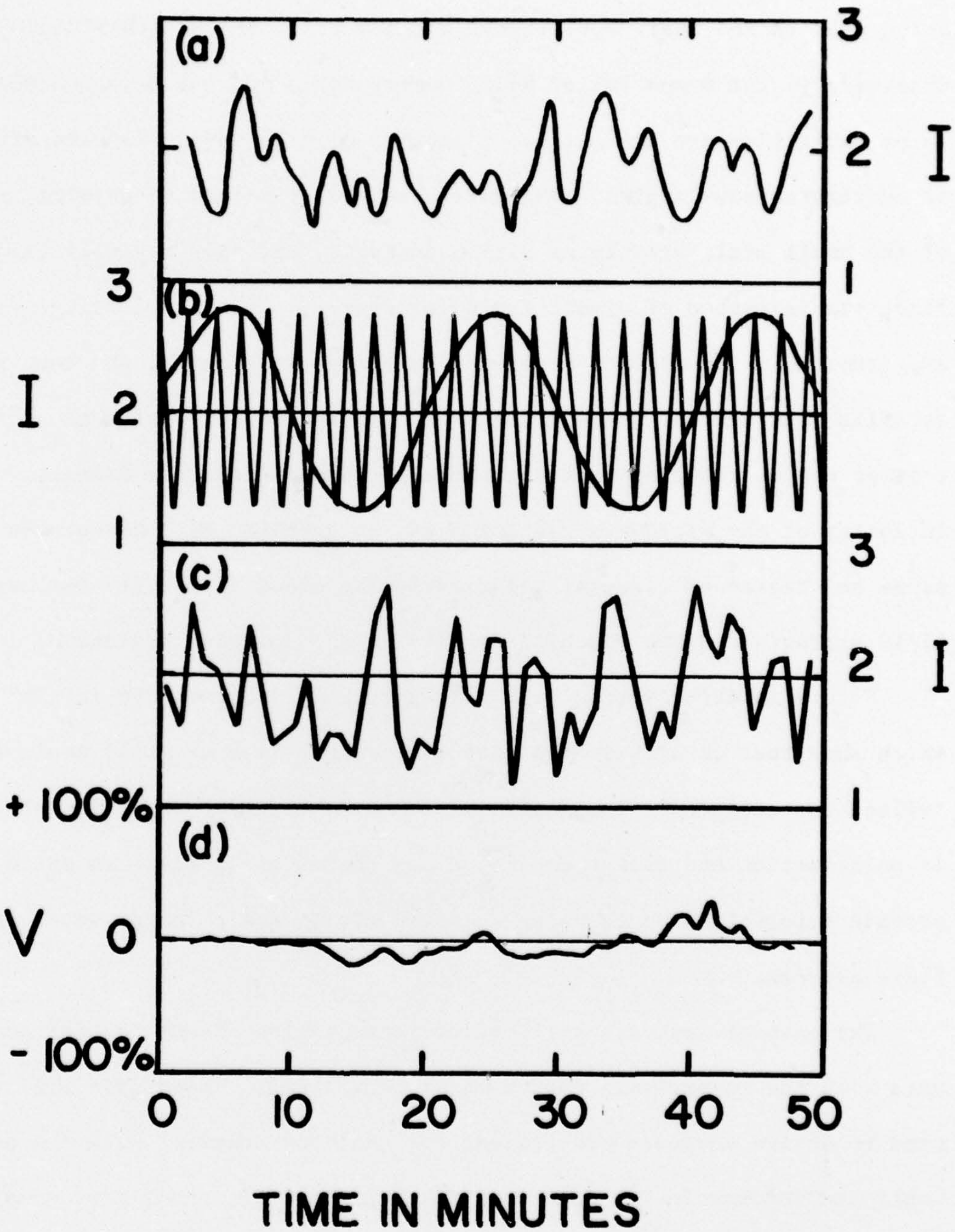
Figure 2. The fluctuating component of the quiet solar disk observed at 3.7 cm wavelength with an antenna separation of 2700 m. Similar fluctuations in total intensity, I, were observed by Kundu and Alissandrakis (a) and the author (c). The units of I are 10^{-23} W m^{-1} Hz^{-1}. A comparison of curves (a) and (c) with curve (b) shows that only a limited range of periodicities can fit the observed data, whereas curve (d) shows that the fluctuating component is less than 10% circularly polarized.

FIGURE 1



4
3
2
1
I, λ = 3.7cm
B = 2700 m
+ 100%
+ 50%
0%
- 50%
∓ 100%
V, λ = 3.7cm
B = 2700 m
+ 50%
0%
- 50%
∓ 100%
Q, λ = 3.7cm
B = 2700 m
+ 50%
0%
- 50%
∓ 100%
U, λ = 3.7cm
B = 2700 m
+ 50%
0%
- 50%
∓ 100%
V, λ = 11 cm
B = 2100 m
+ 50%
0%
- 50%
- 100%
0
50
100
150
200
250
TIME IN MINUTES

FIGURE 2



IV. FUTURE PLANS

The promising results obtained under the support of this contract are being used as the basis for observing requests to the National Radio Astronomy Observatory, the Owens Valley Radio Observatory, and the Haystack Observatory. These facilities are the only ones capable of high resolution interferometry at centimeter wavelengths. The data obtained will lead to physical models of the small scale structures within sunspots, and they may well lead to the first viable method of predicting solar flares. Changes of fringe visibility amplitude as a function of observing baseline, wavelength, and hour angle will establish the size of the emitting regions. The exact positions of these regions can be inferred from the phase of the interference fringes. The intensity of the microwave radiation can be combined with measurements of the sense and degree of circular polarization in order to specify the magnetic field strength and the electron density in the emitting regions.

Future interferometric data will hopefully substantiate initial data which show that changes in the circular polarization of small scale features reflect the emergence of magnetic fields which trigger solar flares. Changes in polarization and fringe amplitude and phase during flare emission will provide information on changing magnetic fields and emission waves during the flare process.

The general approach will be the accumulation of substantial amounts of data with the major radio astronomical facilities. These data will then be used to derive adequate statistical correlations together with the above-mentioned information on sunspots, flare prediction, and flare emission.

V. FISCAL REPORT

Of the total of $7,916 authorized for 12 months, 100% has been expended after 12 months and 100% of the work has been completed.

VI. CONCLUSION

Preliminary interferometric observations of the Sun by the principal investigator suggested that fine scale radio structures within solar active regions exhibit dramatic changes in circular polarization prior to flare emission. (K.R. Lang, "High Resolution Interferometry of the Sun at 3.7 cm Wavelength" Solar Physics 36, 351-367 (1974)) On the basis of these observations a general program was set up under the sponsorship of Contract F 19628-76-C-0020 with the Air Force Systems Command, Hanscom AFB. This one-year program, which terminated June 30, 1976, has been highly successful. Simultaneous measurements of the four Stokes parameters of solar radio emission at wavelengths of λ = 3.7 cm and λ = 11 cm were carried out with angular resolutions ranging from 2.7 to 36.7 seconds of arc. The observations confirmed the emergence of fine scale features with circular polarization changes between 40% and 100% prior to flare emission, whereas no similar changes were observed during five days of quiescent solar activity. It appears that levels of fine scale circular polarization can provide advance warning of solar activity. The work mentioned immediately above has been accepted for publication (K.R. Lang, "High Resolution Polarimetry of the Sun at 3.7 and 11 cm Wavelength", to be published in Solar Physics).